RP 701 Wind Project End of Warranty Management and Inspections

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

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Purpose and Scope

The scope of "Wind Project End of Warranty Management and Inspections" discusses preferred methods used to effectively manage construction workmanship, balance of plant (BOP) equipment, wind turbine, and serial defect warranties. This process includes assessing the condition of BOP equipment and wind turbines prior to the expiration of the original equipment manufacturer (OEM) warranty, commonly referred to as end of warranty (EOW) inspections. This document also includes information useful for following the best practice of performing operational audits and quality control of the service provider post-warranty. It is also recommended that the reader consults applicable IEEE, ASTM, IEC, and other industry guidance and standards.

The transition out of the warranty period is a critical milestone in the life of a wind project. Defects or damage due to design, manufacturing, shipping, installation, and maintenance practices are typically covered under warranty agreements and can often be repaired or replaced during this time so that equipment is in the best possible condition exiting the warranty. It is also important to identify and address any sub-performing aspects of the equipment during this period, which can be of particular significance for new models. Scheduled maintenance inspections may not detect component failures and a more thorough inspection with specialized tools is recommended prior to warranty expiration. The priorities in an EOW inspection are to identify component failures, particularly on the critical and highest costs components, and any items which may pose hazards to equipment or the health and safety of site personnel and to document the condition of the turbines and related equipment for future reference. Claims may result in component replacement or commercial changes to ensure the owner is protected, e.g. an extended warranty on a particular component. Some amount of normal wear and tear should be expected and will not necessarily impact the ability of a component to meet its design life or result in a successful warranty claim.

Purpose and Scope
(continued)

The purpose of this document is to describe recommendations for warranty management and the most appropriate techniques used in EOW inspections. These practices, if properly applied, should lead to the submission of well-documented warranty claims and facilitate effective warranty management.

Introduction

There are many factors and timeframes to consider when planning for effective management of various warranties. There are contractual elements that influence the process, e.g. a serial defect clause may have a different timeframe for exercising rights than the overall warranty timeframe. Main warranty elements of a typical wind project may include the following:

- EPC contractor workmanship
- BOP equipment
- Turbine equipment
- Turbine performance, e.g. sound and power

Management of some of the sub-elements of the main items listed above is more reactionary, whereas others require more pro-active planning, testing, and inspection in order to exercise and maximize warranty rights. However, in all cases, awareness of the various warranty elements and timelines is essential.

The scope of an EOW inspection campaign can range from minimal to complex depending on the time and cost constraints and the interest of the project owner. In addition, utilizing a reputable independent third-party for inspections may add more credibility to the findings. A wide variety of inspection techniques are available and the project owner must decide which are appropriate for their situation. Known issues may exist with a particular component, warranting specific inspection techniques that may not be necessary in all cases. Many equipment warranty items are OEM dependent and industry user groups can provide a useful forum for leveraging pooled information. This can help in warranty claims and in tailoring the end of warranty approach to pre-manage specific known issues. For large projects, it can be beneficial to conduct a diverse range of inspection tasks on a sample population of turbines prior to the full-scale inspection campaign. This can establish the most critical tasks and determine the scope of inspections to be conducted for the entire project.

Introduction
(continued)

Individual inspection tasks during the complete EOW inspection campaign can be completed on 100% of turbines on a project or on a smaller sample population, depending on the criticality, cost, and time required for the particular task. While project-specific circumstances will vary, the best practice is to inspect 100% of major components or any component where there is potential for a serial defect claim. It is advisable that owners take their serial defect threshold definitions into account when deciding how many turbine components to inspect. Some inspection tasks may only be triggered if a problem is identified by other means. For other components, or for QA/QC inspections, the owner should evaluate their risk tolerance, the risk, and their serial defect threshold definitions to decide whether to use 100% inspection or a sampling approach. Evaluation of supervisory control and data acquisition (SCADA) data and review of parts usage at the project is recommended for identifying components or turbines that warrant additional targeted attention during EOW inspections.

Inspections may be conducted by independent third-party organizations, the project owner, or combinations of several groups with specialized skill sets. Representatives from the OEM and/or owner may accompany inspection teams or teams can operate independently. Best practice is to involve site staff, owner's engineers, and the OEM during the initial inspections so the processes can be reviewed and agreed upon by all parties at the onset of inspections.

Inspections are a human process with some subjectivity in discerning between normal wear and tear and actual claims. Note that inspectors generally do not inspect certain items to avoid disturbing their condition. Power performance testing or sound testing may also be considered.

Timing and Planning

Points to consider:

- Contractual elements, such as turbine-by-turbine warranty timing, may not coincide with project wide timing of warranties. Note that serial defect warranty timing may not align with other project warranty timing.
- Consider conducting end of warranty inspections following a maintenance cycle so the inspections can focus more on warranty items rather than items that will be picked up during maintenance.
- Consider timing inspections to maximize the warranty period while allowing sufficient time to make claims.
- Pick timing that will minimize lost energy production due to inspection activity.

Timing and Planning
(continued)

Points to consider:

- Timing of tests may require steps to be initiated prior to completion of construction, e.g. power performance test site calibration, if required.
- Consider effects of daily scheduling, e.g. early morning shifts help avoid the hottest times of day.
- Consider major component spares that may have time-based maintenance and associated warranties.

Balance of Plant (BOP) End of Warranty Inspections

The expiration of warranties for balance of plant equipment and installation may or may not coincide with the wind turbines' OEM warranties. Planning the EOW inspections for the balance of plant should be a consideration. The balance of plant EOW will include the collection system, substation, civil site improvements, O&M building, and met mast.

1. Procedure

1.1. Obtain a complete drawing package for collection system to ensure correctness and completeness.

1.2. Determine the expiration dates and allow for sufficient time to conduct the inspections, analyze the results, and file any necessary claims.

1.3. EOW inspections should include a review of the contractor turnover package and site maintenance documentation to understand the as-built condition and what has occurred while the equipment and site were under warranty.

1.4. Based on a review of the documentation as mentioned above, determine the scope and scale of the BOP inspection. Inspections may be for the total site or a representative sample of each area.

1.5. Agree on the personnel that will be involved: OEM technicians, third-party inspection, site operator, and owner's representative.

2. Safety

2.1. Provide suitable safety precautions and protection per Occupational Safety and Health Administration (OSHA) regulation and appropriate consensus standards during field testing. Only trained and qualified personnel shall operate test equipment.

2.2. All lock out/tag out (LOTO) procedures shall be strictly adhered to, along with minimum approach.

2.3. Markings/labels for safety should meet all codes.

2.4. Ground equipment and discharge to make them safe after high potential testing.

2.5. Arc flash detector should be tested to meet original operational standards and industry regulator requirements.

2.6. Fire extinguishers should be certified and record keeping should be in place to meet International Code Council (ICC) Section 306 Factory Group F, which requires 30-day testing or electronic monitoring.

2.7. Ensure the project site and equipment OEM safety procedures are followed.

2.8. Visually monitor for excessive housekeeping issues, such as signs of grease or oil spills and general uncleanliness leading to masked problems.

2.9. Reference the "*AWEA Qualified Electrical Worker Guideline and Unqualified Electrical Worker*" document.

3. Pad Mount Transformer (PMT)

3.1. As a wind power generation component, the PMT is developing a history of causing outages. This should be a component of particular attention for EOW.

3.2. Audible testing for transformer wear and tear that could result in catastrophic damage should be performed prior to opening cabinet.

3.3. Visually inspect the exterior noting: levelness and integrity of the pad and ground rod connections, condition of the surrounding backfill, condition of barrier posts, evidence of corrosion, encroachment of vegetation, evidence of oil leakage, and paint.

3.4. Inspect the pads and/or vaults.

3.5. Bollards/fences shall be installed and in good operational condition to protect from vehicle and large animal intrusion to the outer enclosure.

3.6. Proper grouting and leveling of transformer opening in the ground should be inspected using appropriate ground leveling techniques. Suitable products should be added to ensure outside elements such as dirt/dust, moisture, and living insects and animals cannot get into the space.

3.7. Proper cable conduit fill materials should be used to ensure moisture, insects, and animals cannot get into the air space compartments through these items. Common putty does not work when heated and deteriorates.

3.8. Original oil containment systems should be inspected and repaired. If no containment is installed originally, a plan for reaction to oil spills should be in place.

4. De-Energized-Energized Inspection and Pre-Turnover Testing

4.1. Energized and de-energized check the oil. Transformers should have gauges for level, minimum, and maximum temperature.

4.2. Pre-turnover test should be made for dissolved gas analysis (DGA) and comparison or trending of the DGA reports.

4.3. Energized with load infrared (IR) scans of terminations to check for connection integrity or load imbalances, preferably at greater than or equal to 75% load.

4.4. Non-energized test of tap changer should be cycled for confirmation of smooth movement.

4.5. NO-LOAD energized test of tap changer should be cycled for confirmation of smooth movement using appropriate safety equipment.

4.6. Non-energized ON-OFF-alternate POSITION changer should be cycled for confirmation of smooth movement.

4.7. Energized ON-OFF-alternate POSITION changer should be cycled for confirmation of smooth movement using appropriate safety equipment.

4.8. Energized operational tests should be conducted in accordance with International Electrotechnical Commission (IEC) and/or American Society for Testing Materials (ASTM) standards using appropriate safety equipment.

4.9. Low voltage (LV) connections should be torque tested. Cable connections to connectors should be inspected for heat damage and other wear.

4.10. Medium voltage (MV) connectors should be removed and cleaned to properly inspect for arcing and other deterioration. Darkening for heating should be checked. MV bushings should be visibly inspected for arcing and deterioration. Grounding of connectors should be inspected and repaired as necessary. Replace questionable connectors. MV surge arrestors should be visibly inspected for wear and tear. Testing is not generally performed.

4.11. Low voltage (LV) and high voltage (HV) bushings should be checked for visible arcing and oil leaking. Check for gravitational pulling on cables that could potentially result in bushing leaks. Cable mounting systems should be installed to preclude or eliminate leaks.

4.12. LV circuit breakers, where used, shall be inspected according to the manufacturer's maintenance and operations specifications. Visually inspect terminations, mounting connections, cleanliness from dust, corrosives, and evidence of living matter. Manually inspect operation of breaker and complete factory service as prudent or required.

5. Collection System

5.1. Review as-built drawings and verify installation of underground system from contractor turnover documentation. Ensure as-built meets the standards of the engineer's drawings. Record deviations.

5.2. Obtain a full list of components and develop a necessary spares inventory.

5.3. Review full incident history of collection system faults, trips, and repairs.

5.4. Overhead systems:

5.4.1. Develop a fill list of components of poles and hardware including torque specifications weights and measures.

5.4.2. Develop a critical spares list for inventory needs and turnover spares requirements.

5.4.3. Visually inspect wooden poles for degradation from construction or environment.

5.4.4. Visually inspect insulators, cross arms, arrestors, and overhead connectors for structural integrity and electrical wear and tear, arcing, and corrosion.

5.4.5. Inspect all cable connections for wear and proper installation methods.

5.4.6. Inspect the overhead system for proper catenary of the cabling.

5.4.7. Use Thermal Imaging on each electrical connection for hot spots.

5.4.8. Disconnect switches should be operated de-energized. The fuse should be verified as to operation and proper size per drawings and engineering requirements.

5.4.9. Instrument transformers such a current transformers (CT) and voltage transformers (VT) should be visually and mechanically inspected. Ratio tests should be made according to the manufacturer's standards and engineering requirements.

5.4.10. Automatic pole mounted equipment should be inspected visually for damage and connections. The device should be mechanically and electrically operated while de-energized and while energized per manufacturers operating instructions and wind farm grid operator advice.

5.4.11. Cable risers for underground cables to pole line should be inspected de-energized for integrity of electrical and mechanical connections including any cable covers, cable hanging methods, jumper connections and cleanliness of insulators. IR testing inspection should be used during energized and under power certification of integrity.

5.5. Underground system

6. Develop a fill list of components, poles, and hardware including torque specifications, weights, and measures.

7. Inspect junction boxes for mechanical integrity and operation including:

7.1. Level

7.2. Surrounding earth integrity

7.3. Electrical grounding integrity

7.4. Paint

7.5. Fault indicator operation and integrity including viewports when used

7.6. IR test when energized and under load

7.7. Wear and tear on mechanical devices and bolting locations

7.8. Visible inspection of MV connectors and cable including evidence of arcing, excess wear, cuts, or physical damage

7.9. Manual application of cable connectors to ensure they are not too loose or too tight (won’t rotate or remove)

7.10. Inspection of arrestors and other apparatus inside or outside enclosure

8. Visually inspect cable splices (if available) and terminations.

9. Perform IR Scans and/or bolt torque tests in accordance with the EOW plan.

10. Perform VLF system testing after component acceptance testing is complete to verify that all cabling systems operate properly.

10.1. Notify owner/customer in advance to allow witnessing.

10.2. May also include partial discharge (PD) testing on collection systems.

11. Substation

11.1. All applicable inspections and test reports shall become part of the EOW documentation to the owner/customer.

11.2. Grounding system:

11.2.1. Use instruments to test for proper ground value per engineer's requirements.

11.2.2. A visual and mechanical inspection of grounding system shall be conducted to ensure grounding cable, ground rods, and exothermic or mechanical ground connection(s) are in compliance with engineer drawings and specification.

11.3. Foundations:

Conduct a visual inspection noting: levelness and integrity of the pad, condition of the surrounding backfill, condition of barrier posts, evidence of corrosion, and encroachment of vegetation to ensure foundations are consistent with design requirements. Include bolt torque checks.

11.4. IR scans:

11.4.1. IR scans are effective when above about 75% load.

11.4.2. Scan the entire substation looking for temperature anomalies. Check all electrical connections in the substation yard, as well as in the control house.

11.4.3. Weather conditions can be very important and can mask potential issues. Bright sun, significant wind, or precipitation can affect thermal imaging inspections. Note the conditions during the inspection.

11.4.4. Inspect the bushings. Look for heat in the external connections, internal connections, in the bushing head, and connections to the coils.

11.4.5. Check the surge protection. Look at segmented signatures with small rises in temperature as indicators of serious problems.

11.4.6. Inspect the cooling systems. Blockage or low oil in radiators will show up as cool tubes.

11.4.7. Inspect the fans after they have operated for 15 minutes or more.

11.4.8. Check all oil-filled circuit breakers (OCB) and voltage regulators. Check the tank differentials top-to-bottom and tank-to-tank.

11.4.9. Inspect all disconnects and switches.

11.5. Circuit breakers:

Inspect and test per OEM manual; ensure properly commissioned. Check for loose wiring connections and perform full functional and insulation testing.

11.6. Current transformers (CTs):

Confirm CT ratios and metering accuracy.

11.7. Metering equipment:

Confirm accuracy with secondary meter.

11.8. Voltage transformers/potential transformers:

Check oil levels and electrical connections. Verify secondary voltages.

11.9. Capacitor banks:

Confirm all connections. Visually inspect all packs for bulging and leaks. Verify bank capacitance.

11.10. Battery banks and charging systems:

Check all cells for plate damage. Test for internal resistance and specific gravity of each cell. Verify battery charger operation by applying charge cycle to battery bank.

11.11. Reactors:

Check all connections and perform a visual inspection for any abnormalities.

11.12. Generator step-up transformer (GSU) main power transformer:

11.12.1. Verify condition of all control cabinet wiring.

11.12.2. Perform partial discharge testing.

11.12.3. Perform dissolved gas and comprehensive oil analysis on the main tank and load tap changers (LTC) compartments.

11.12.4. Check for oil leaks and oil levels on all oil compartments and all oil filled bushings.

11.12.5. Perform complete power factor (PF) testing to confirm winding and bushing insulation condition.

11.12.6. Perform exciting current and leakage reactance impedance tests.

11.12.7. Analyze LTC condition based on oil sample and heat signature data.

11.12.8. Verify all alarms and transformer trip circuits.

11.12.9. Verify correct connectivity and operation of the controls building and communication systems.

11.12.10. Verify relays (hardware and software). Verify all software versions are up to date. Verify all relay operations and trip paths. Verify all relays & meters (pickups, timing, logic, SCADA, and targets), functional trip/close, and I/0 testing.

11.12.11. Verify operation and condition of all sump and secondary containment systems.

12. Civil Site Improvements

12.1. Review the storm water pollution prevention plan (SWPPP). By this time the construction plan should have been converted to a post-construction storm water management practice plan.

12.2. Inspect the site best management practices (BMP) for adherence to the SWPPP.

12.2.1. Ensure that the temporary construction BMPs have been removed.

12.2.2. Ensure that the permanent storm water management structures are in place and void of construction sediment.

12.3. Inspect the site roads, culverts, and bridges for structural soundness. This may also be an opportune time to mitigate any unforeseen erosion or other issues.

12.3.1. Ensure that the road width is in accordance with site permits.

12.3.2. Ensure that reclaimed construction areas are properly vegetated.

12.3.3. Ensure that the areas adjacent to each wind turbine are in accordance with the design and local requirements.

12.3.4. Look for areas of erosion. Ensure proper drainage.

1.13. Meteorological Tower

13.1. Review the commissioning documentation.

13.2. Establish protocols and execute inspections to verify operational accuracy.

13.3. Inspect foundation, guy wires, and anchor points for structural integrity, condition of the backfill, and condition of the surrounding immediate area.

13.4. Visually inspect the tower looking for structural faults and corrosion.

13.5. Ensure that cabling is installed in accordance with the design parameters.

13.6. Ensure that all instruments are working as designed.

13.7. Check power supply and any backup power. Check communications.

13.8. Check that FAA lighting functions appropriately. Verify record keeping for FAA requirements.

14. Operations and Maintenance (O&M) Building

14.1. Verify permits are in order.

14.2. Verify all drawings and documentation are available and in order for all equipment.

14.3. Inspect the structural components of the foundation and building for structural integrity.

14.4. Inspect each operating system: safety, electrical, plumbing, computer, and communications for adherence to the design, drawings, and use of specified or accepted components.

14.5. Check oil storage areas for containment, ventilation, and compliance.

14.6. If applicable, the back-up generator may have a warranty.

15. Gen-tie Line

15.1. Insulator IR scans and visual inspections

15.2. Structural integrity

15.3. Static line (lightning protection)

15.4. Communication line

15.5. Conductor line sag

15.6. Avian deterrents

15.7. Bird diverters, if applicable

16. Communications/SCADA

16.1. Verify redundancy is functional

16.2. UPS

16.3. Cooling system functionality, if applicable

Wind Turbine End of Warranty Inspections

1. Common Inspection Items

1.1. Safety Equipment

Depending on the scope of supply, the warranty may be with the turbine OEM or with the equipment supplier. Items may include:

- Markings/labels for safety should meet all codes.
- Switchgear and transformer arc flash detectors
- Ladder and safety cable (limited fall arrest system) and lifts
- First aid kits complete and dated
- Fire extinguishers
- FAA lights
- Emergency descent devices (check for wear and tear and meeting standards from OSHA and other safety regulators.)
- Housekeeping and spills can be indicative of issues.

1.2. Drivetrain

1.2.1. Gearbox

Borescopes are commonly used to document the condition of gear teeth and bearings within the gearbox. Borescope inspection is recommended for gearboxes. Borescope images should be taken in all accessible areas of the gearbox, regardless of whether or not damage exists, to document the condition. Images should include the gearbox nameplate, and reference photo cards should be used to identify each section of the gearbox. Images of each component should be taken in a consistent order for all gearboxes. Areas of the gearbox that cannot be accessed should be noted, and images of obstructions taken where appropriate, such as a bearing cage blocking inspection of bearing races.

Image quality should be the most important factor in borescope selection, as some borescopes are inadequate for wind turbine gearbox inspections. The rigidity of guide tubes, lens cleanliness, the type and quality of light, and, particularly, technician training, all affect image quality.

The time required for a borescope inspection is highly variable depending on access, operator skill level, and the number of positions in which the gearbox will be stopped to permit inspections.

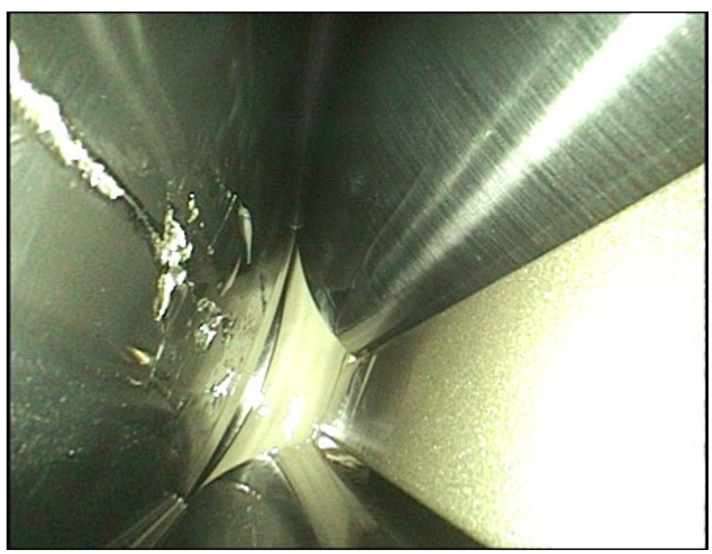

Figure A: Example of Damage to the Inner Race of a High Speed Bearing Documented with a Borescope.

1.2.1 Gearbox
(continued)

Additional elements of a gearbox inspection should include visual inspection of the housing for cracks and leaks, damaged ancillary equipment, oil level in the sight glass, and magnets. Any abnormal color, smell, or foam in the oil should also be noted at the time of inspection.

1.2.2. Main Shaft

Visually and functionally inspect the brake assembly for proper operation. This can include making sure that rotor locking pins can be inserted correctly and that the brake operates as expected.

Visually inspect the high-speed flexible coupling between the gearbox and generator. Verify that bolts have torque marks and that the coupling has been aligned and installed correctly according to the coupling OEM’s installation manual.

1.2.3. Main Bearing

Visually inspect the main bearing and record any signs of leakage from the seals. Inspect the grease trap and note signs of excessive grease or grease that is discolored or appears shiny. Grease samples can be taken from the main bearing and sent to a lab for analysis.

Temperature trending of the main bearings can also be used to target certain bearings for inspection. Signs of gradual temperature rise over time or temperatures that appear higher than the rest of the site are good candidates for further inspection.

Vibration analysis can also be done on the main bearing. It is important to note that, since the main bearing is a low-speed component, this analysis is limited in its effectiveness in finding issues and will need to be done in concert with the other inspection techniques described in this section.

A borescope may also be used in some cases to look at the internal sections of the main bearing. This can provide detailed pictures similar to gearbox borescopes showing internal damage.

1.3. Bland Inspections: Done

Visual inspection of the blade surface is commonly conducted from the ground and at the blade surface using various access techniques. One hundred percent of turbine blades should be inspected. Each blade should be photographed with images covering the entire surface and from different angles so the leading edge, trailing edge, and high and low-pressure surfaces are all clearly visible. Using a camera is preferable to a spotting scope or binoculars, as a camera provides documentation that can be reviewed by others and, in some cases, damage may not be evident until post processing of the images is done. Drone camera inspections are also an option and may be more cost effective depending on the site conditions present. Several (5-10) complete rotors can be completely documented by an experienced crew in a day. Inspection of all blades is recommended.

Figure B: Example of Blade Damage Documented with Ground-based Digital Photography.

1.3. Bland Inspections - Done
(continued)

Direct access inspections, e.g. ropes, platforms, boom trucks, etc., can be used to detect damage that may not be visible in ground-based images, e.g. small cracks. In some cases, the extent of damage may not be clear in ground-based images and can be clarified through direct access inspections. Ultrasonic testing (UT) or other non-destructive techniques that can detect the presence of other defects and voids in adhesive bonds can also be performed during direct access inspections. A single crew can typically inspect 1-2 rotors per day but these inspections impose greater limitations on safe working conditions, e.g. wind speed limits, so a sample of 10-20% of the project is often more feasible.

It is recommended that the inspections ensure that the lightning protection system (LPS) is functioning as intended.

Consider whether internal blade inspections are required noting this may be considered a permit required confined space.

1.4. Turbine Electrical

Verify all power connections are tight to manufacturer's requirements. Verify general cleanliness of enclosure(s) interior. Inspect all wiring, power, and control for evidence of high heat and poor connections at each end. Verify communications wiring is in good condition and properly physically placed and connected. Verify sub-distribution equipment including contactors, circuit breakers, fuse/holder, terminal blocks, surge arrestors, transformers, fans, capacitors, and all other operation-critical components are in good working condition.

1.4.1. Power Converter

Visually inspect the power converter of the turbine and ensure that all wiring is organized, routed, and terminated correctly. Inspect wires for signs of damaged insulation and note any wires that are not labeled at the spot of termination. This may indicate the presence of a jumper wire that may be bypassing certain controls.

1.4.1. Power Converter
(continued)

Verify all power connections are tight to manufacturer's requirements. Verify general cleanliness of enclosure(s) interior. Inspect all wiring, power, and control, for evidence of high heat and poor connections at each end. Verify communications wiring is in good condition and properly physically placed and connected. Verify sub-distribution equipment including contactors, circuit breakers, fuse/holder, terminal blocks, surge arrestors, transformers, fans, reactors, capacitors, and all other operation-critical components are in good working condition. Check for cleanliness internally and externally.

From records or onboard database, review the number of operations and various trip reasons looking for high energy trips to resolution. Verify factory required maintenance performance schedule. Verify wiring of accessories are tight and clear of heat or fault damage. Test according to manufacturer's instructions.

Visually inspect the heat exchanger system and note any signs of damage to the cooling fins or fans used to remove heat from the power converter. Verify cooling system is fully operational to factory and manufacturers standards. Note replacement history records indicating repetitive failure modes and results.

For liquid-cooled power converters inspect for signs of leakage and ensure that the system has been filled to the correct level and purged of air for proper operation.

1.4.2. Medium Voltage (MV) Switchgear, Where Used

Complete battery of operational testing per manufacturer's requirements including remote trip mechanism and system. Visually inspect accessory wiring, MV connections, and communications, where used.

1.4.3 MV Uptower Transformers, Where Used

Complete battery of operational testing per manufacturer's requirements. Visually inspect MV connectors for wear and damage. Visually inspect for signs of rust and/or oils. Monitor gauges when available. Inspect accessory wiring and accessory monitoring equipment where used. Perform insulation test.

1.4.4. Low Voltage (LV) Control

Work from as-built drawings and factory specifications to inspect:

- **Main Power Panel:** Visually inspect exterior of main control panel breakers for wear and tear, corrosion, and functionality of moving mechanical parts.
- **Main Circuit Breaker:** Check for cleanliness externally and externally. Verify from records or onboard database number of operations and various trip reasons looking for high energy trips to resolution. Verify factory required maintenance performance schedule. Verify wiring of accessories are tight and clear of heat or fault damage. Verify proper lubrication. For draw-out breakers perform complete in/out operation visually inspecting tracks, motion, lubrication and the electrical contacts and connections are in good working order within wear standards. Test according to manufacturer's instructions.
- **Main Contactor:** Check for cleanliness externally and externally. Verify from records or onboard database number of operations. Verify factory required maintenance performance schedule. Verify wiring of accessories are tight and clear of heat or fault damage. Verify proper lubrication. Perform complete operation visually inspecting tracks, motion, lubrication, and the electrical contacts are in good working order within wear standards. Test according to manufacturer's instructions.

1.5. Walk-Down Inspection

A walk-down inspection of the complete turbine is recommended to document safety issues, the general turbine condition, and component failures. Walk-down inspection is recommended for 100% of turbines. A common checklist and rating system for findings to be used for all turbines on a project should be developed with input from the inspection team, owner, site managers, maintenance staff, and the OEM. Checklists provided by the OEM for regular maintenance are a useful starting point for development of the walk-down inspection checklist. Digital images of any observed damage should be collected in addition to the checklists.

1.5. Walk-Down Inspection
(continued)

Inspection crews should have access to turbine controls to be able to test certain systems for function, such as yaw motors, fans, pumps, and brakes. A walk-down typically includes inspection of cables and general housekeeping and checking valves for leaks and function. Some areas of the turbine require specialized training or equipment to access, such as transformers located in nacelles.

During the walk-down inspection, it is recommended to conduct calibration checks of turbine alignment into the wind and calibration of pitch angles. Nacelle and tower inspection checklists are recommended to include inspection structural elements including inspecting the bed plate, tower welds, nacelle structure, nose cone, and fiberglass for cracks.

During the walk-down, check for corrosion on tower sections, cracks in grout (if in use), bolt covers for integrity, and any peeling coatings or corrosion particularly at the touch-up areas. If required, conduct pull tests to ensure bolts meet proper pre-load.

During the walk down inspection, inspect the full array of tower components including heating systems, insulation, anchor points, filters, louvers, decks, hatches and doors, and gantry cranes.

Check for appropriate storage of nacelle access ladder, if applicable.

For the turbine hydraulic, inspect hydraulic water and oil systems of the pitch, yaw, oil cooling, generator cooling, electrical connections, and monitoring for operation, leakage, and general uncleanliness, which may indicate unresolved problems.

All bushings require visual inspections, grease inspections, leak inspections, and a check of the torque marks.

1.6. Retrofits/Upgrades/Software/Firmware

As part of the end of warranty process, it should be confirmed that all applicable manufacturer retrofits and upgrades have been implemented at the site. Best practice includes auditing the software, firmware, and programmable logic control (PLC) programming revisions on each turbine to confirm they are consistent and up-to-date. This recommendation also applies to converter software.

1.7. Pitch System

The type of pitch system (hydraulic or electric) will dictate the specifics of the appropriate inspection methods. Samples of hydraulic fluid may be taken for analysis. Battery systems may require inspections.

- Pitch bearing grease samples may need to be taken.
- Inspect pitch system control cabinets and hardware. Verify mounting system integrity.
- Inspect teeth for wear and cracks.
- Inspect pitch encoder position.
- Inspect pitch accumulators and cylinders for integrity, leaks, appropriate fill levels, dust covers, and oil leaks.
- Inspect pitch motors, gearbox, batteries, and chargers.

1.8. Yaw System

- Where applicable, check puck measurements for uneven wear and cracks.
- Visually check yaw encoder.
- Inspect for excessive wear or cracks in gear teeth.
- Inspect motors, gearboxes, drives, and braking system.
- Inspect the lubrication system.
- Inspect yaw bearing grease samples as applicable.

1.9. Lubricant Sampling and Testing: Done

Sampling and testing of gearbox oil and main bearing grease should be conducted as part of the EOW inspection if this is not already being done as part of regular maintenance or if laboratory reports are not made available to the project owner. Laboratory testing can identify wear metals in the lubricant, the condition of the lubricant itself, and may indicate possible damage to the equipment. The presence of water, changes in viscosity, and additive breakdown can result in a failure of the lubricant, which is, in itself, a critical system. Hydraulic oil, blade bearing grease, and other lubricants may also be sampled and tested as needed. Detailed procedures for lubricant sampling and testing are described in RP 812 and RP 813.

1.10. Generator Testing and Inspection

Electrical testing of the generator can be done with specialized tools and may detect problems with winding insulation, although the ability of these tests to predict failure is limited. A description of specific tests can be found in RP 203. The condition of generator cable terminations may also be inspected and signs of previous arcing identified during testing.

In some cases, it may be possible to inspect generator internals with a borescope, where evidence of arcing, dust generated from loose wedges, and excess grease or debris may be observed and documented. Consider inspections for fatigue cracks of components, the insulation, and windings with a borescope. A generator alignment check may be conducted. Reference “Collector Assembly (Slip Rings and Brushes)” in RP 201. Also reference “Generator Alignment” in RP 205.

1.11. Vibration Measurement: Done

Vibration data, also called condition monitoring system data, can be valuable in detecting faults in parts of the drive train that may not be otherwise accessible. Data from a permanently installed system are preferable as they allow for long-term trending; however, portable vibration systems which can be installed temporarily for EOW inspections may still detect many faults. Vibration data alone will typically not be sufficient to make a warranty claim, but identification of faults through vibration may trigger additional focused borescoping or other inspection techniques which may be impractical to conduct site-wide, such as a partial bearing disassembly and cleaning. Additional information on vibration measurement can be found in RP 204 and RP 811.

2. EOW Inspection Schedule

Inspections should be planned such that delivery of final inspection reports can be made well before the warranty expiration; however, warranty claims can be made at any time before the expiration if sufficient evidence is available. Consult the project contacts to be aware of notification and any timing requirements. Warranty claims will need to be reviewed by the OEM, and not all claims will be accepted, so including ample time for discussion after claims are made but before the warranty has expired is critical. Planning for delivery of inspection results prior to the warranty expiration is considered best practice. Note that notification for serial defect claims should be made as soon as the thresholds are reached; this should not wait until the end of the contract period.

Multiple teams with specialized inspection skills may be deployed across the site and the sequence of deployment is critical to ensure the initial teams provide information to subsequent teams. For example, ground-based blade inspections will inform the choice of turbines that receive direct-access blade inspections. Inspection teams should be given complete access to the turbines and trained to safely stop and control equipment as required for inspections.

3. EOW Reporting

Large amounts of data are generated during an inspection campaign and it is critical to distill the raw data into reports that can be used by project owners to make claims and provide sufficient information for the OEM review. A project-wide executive summary should be produced that identifies the most critical observations and patterns of abnormal wear or damage. The summary report should describe the inspection methods and tools used, nomenclature employed, criteria for classifying observations, photographs, and inspection coverage for all tasks.

Detailed individual turbine reports for each inspection task should also be generated which clearly document the observed conditions. These detailed reports should document the make, model, and serial number(s) of major components, date of inspection, tools used, and the names of the inspectors. For example, each turbine should have a unique borescope inspection report that includes representative images from each section of the gearbox and clearly identifies any damage.

3. EOW Reporting
(continued)

All raw data should be retained and provided to the project owner. These data may be required during the claim process and can be used to benchmark the turbine condition for future reference.

Users need to decide on the amount of data they want to collect.

Summary

Proper EOW management and inspections are effective for documenting the equipment condition in detail prior to warranty expiration and should be performed on all wind projects. A large number of inspection techniques can be deployed as part of an EOW inspection campaign and project owners must consider which are appropriate for their project.

Chapter 8 Condition Based Maintenance

Operations and Maintenance
Recommended Practices

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